

## Chapter 9

### Post-Closure Maintenance and Site End Use

#### 9.1 Introduction

After a cover system has been constructed, it must be monitored and maintained for some timeframe (i.e., the post-closure period). As discussed in Sections 1.2.6 and 8.1, post closure maintenance must be conducted as long as the waste poses a threat to human health and the environment. The post-closure period of 30 years given in RCRA regulations has generally been considered by EPA to be the minimum timeframe for performance monitoring and maintenance for MSW and HW facilities. For CERCLA facilities, the minimum timeframe for cover system maintenance and monitoring is also often assumed to be 30 years, and the EPA is required to evaluate the performance of the cover system at least once every five years to assure that human health and the environment are being protected by the implemented remedy.

Regulatory requirements for post-closure maintenance of MSW landfill cover systems are contained in 40 CFR §258.61 (a)(1):

*“(a) Following closure of each MSWLF unit, the owner or operator must conduct post-closure care. Post-closure care must be conducted for 30 years, except as provided under paragraph (b) of this section, and consist of at least the following:*  
*(1) Maintaining the integrity and effectiveness of any final cover, including making repairs to the cover as necessary to correct the effects of settlement, subsidence, erosion, or other events, and preventing run-on and run-off from eroding or otherwise damaging the final cover.”*

For MSW landfills, 40 CFR §258.61 (b) provides the following flexibility with respect to the length of the post-closure period:

*“(b) The length of the post-closure care period may be:*  
*(1) Decreased by the Director of an approved State if the owner or operator demonstrates that the reduced period is sufficient to protect human health and the environment and this demonstration is approved by the Director of an approved State; or*  
*(2) Increased by the Director of an approved State if the Director of an approved State determines that the lengthened period is necessary to protect human health and the environment.”*

Analogous requirements for HW landfills are contained in 40 CFR §264.310 (b)(1) and (5). Regulations for MSW landfills presented in 40 CFR §258.61(c) and regulations for hazardous waste facilities presented in 40 CFR §264.118 require facility owners or operators to prepare a written post-closure plan that includes a description of the post-closure maintenance activities and the frequency of such activities. The purpose of these activities is to ensure the integrity of the cover system and functionality of any monitoring equipment. Maintenance activities include those conducted in response to observations made during periodic inspections and monitoring

DRAFT - DO NOT CITE OR QUOTE

and scheduled routine activities, such as pump maintenance or replacement. An example of a post-closure inspection, monitoring and maintenance schedule is presented in Table 9-1. An example of a post-closure inspection form, used by the U.S. Army Corps of Engineers, is presented in Table 9-2. This table can be used to document the condition of a landfill cover and identify any required post-closure maintenance activities. In addition to regularly scheduled inspections, a thorough inspection of the cover system should be conducted after major storm events.

The maintenance (and monitoring) activities to be conducted at a closed waste containment facility or remediation site depend on the end use of the site. For example, as discussed in Section 9.3.5, when a mountain bike challenge course was constructed on top of a cover system, routine cover system maintenance included repairing ruts made by the bike tires. It is recommended that personnel conducting the maintenance activities be familiar with the function of the cover system, rather than only familiar with the site end use (e.g., sports facility). If maintenance is not correctly performed, cover system or monitoring system integrity may be impaired.

**Table 9-1. Example of waste containment facility or remediation site monitoring and maintenance schedule.**

<b>Component</b>	<b>Inspection and Monitoring Frequency<sup>1</sup></b>	<b>Methods<sup>2</sup></b>
Cover System Vegetation	Monthly	Visual
Cover System Erosion	Monthly and After Major Storms	Visual
Cover System Intrusion	Monthly	Visual
Cover System Subsidence	Quarterly	Visual
Cover System Slope Stability	Quarterly	Visual
Cover System Drainage Outlets	Quarterly	Visual
Cover System Grades (Survey)	Every 5 Years	Survey/GPS
Gas Extraction System	Monthly	System Check
Surface-Water Management System	Quarterly and After Major Storms	Visual
Leachate Collection and Removal System/ Leak Detection System	Monthly	System Check
Perimeter Security (fence, gate, locks)	Quarterly	Visual
Access Roads	Quarterly	Visual/RT/PC
Groundwater Monitoring System	Quarterly	System Check
Gas Monitoring System	Quarterly	System Check
Survey Monuments	Annually for First 5 Years, at 5 Year Intervals Thereafter	Survey
Post-Earthquake Condition of all Systems/Structures	After Earthquakes	All Above

<sup>1</sup>Frequency of inspection and monitoring may be reduced (or increased) based on observed conditions during the post-closure period.

<sup>2</sup>GPS = global positioning system; RT = rut depth for unpaved roads; and PC = pavement cracking for paved roads.

This chapter discusses cover system maintenance and site end use. Other types of post-closure maintenance activities typically associated with waste containment facilities or remediation sites are not addressed herein. These include maintenance of leachate collection and removal systems, leak detection systems, groundwater monitoring systems, and gas management and monitoring systems. The condition of these systems must be monitored during the post-closure period to assure adequate performance of the site in the long term and to comply with various regulatory requirements.

**Table 9-2. Example of post-closure monitoring form used by U.S. Army Corps of Engineers for CERCLA sites.**

<b>Site Name:</b>	<b>Date of Inspection:</b>
<b>CERCLIS ID:</b>	<b>Weather:</b>
<b>State:</b>	<b>Temperature:</b>
<b>Corps Construction District:</b>	<b>Corps Design District:</b>
<b>EPA Region:</b>	<b>Site Map: Attach</b>
<b>Inspection Team: Attach Roster</b>	<b>Note: Indicate the location of any deficiency noted below on the site map</b>
<b>ITEM</b>	<b>REMARKS</b>
<b>COVER SYSTEM SURFACE</b>	
<b>1. SETTLEMENT (LOW SPOTS)</b> Yes ( ) No ( ) Areal Extent: Depth:	
<b>2. CRACKS</b> Yes ( ) No ( ) Length: Width: Depth:	
<b>3. EROSION</b> Yes ( ) No ( ) Areal Extent: Depth:	
<b>4. HOLES</b> Yes ( ) No ( ) Areal Extent: Depth: Suspected Cause (Rodent or Other):	
<b>5. VEGETATIVE COVER</b> Yes ( ) No ( ) Grass: Yes No Condition: Trees/Shrubs Yes ( ) No ( ) Size:	
<b>6. ARMORED COVER</b> Yes ( ) No ( ) Material Type: Condition:	
<b>7. BULGES</b> Yes ( ) No ( ) Areal Extent: Height: Suspected Cause (gas pressure or other):	
<b>8. WET AREAS</b> Yes ( ) No ( ) Ponding: Yes ( ) No ( ) Areal Extent: Seeps: Yes ( ) No ( ) Areal Extent: Estimated Flow Rate: Soft Subgrade: Yes ( ) No ( ) Areal Extent:	
<b>9. SLOPE INSTABILITY</b> Yes ( ) No ( ) Slides: Yes ( ) No ( ) Areal Extent: Probable Slide Interface: Suspected Cause: Exposed Cover Components:	

**Table 9-2. Example of post-closure monitoring form used by U.S. Army Corps of Engineers for CERCLA sites (cont).**

<b>BENCHES</b>	
<b>1. FLOW BYPASS BENCHES</b> Yes ( ) No ( ) Description of problem:	
<b>2. BENCH BREACHED</b> Yes ( ) No ( ) Description of problem:	
<b>3. BENCH OVERTOPPED</b> Yes ( ) No ( ) Description of problem:	
<b>LETDOWN CHANNELS</b>	
<b>1. SETTLEMENT</b> Yes ( ) No ( ) Areal Extent: Depth:	
<b>2. MATERIAL DEGRADATION</b> Yes ( ) No ( ) Material Type: Areal Extent: Degree of Degradation:	
<b>3. EROSION</b> Yes ( ) No ( ) Areal Extent: Depth:	
<b>4. UNDERCUTTING</b> Yes ( ) No ( ) Areal Extent: Depth:	
<b>5. OBSTRUCTIONS</b> Yes ( ) No ( ) Type: Areal Extent: Size:	
<b>6. SLOPE INSTABILITY</b> Yes ( ) No ( ) Type: Areal Extent:	
<b>COVER PENETRATIONS</b>	
<b>1. GAS VENTS</b> Yes ( ) No ( ) Active ( ) Passive ( ) Functioning: Yes ( ) No ( ) Condition: Routinely Sampled: Yes ( ) No ( )	
<b>2. GAS MONITORING PROBES</b> Yes ( ) No ( ) Functioning: Yes ( ) No ( ) Condition: Routinely Sampled: Yes ( ) No ( )	
<b>3. MONITORING WELLS</b> Yes ( ) No ( ) Functioning: Yes ( ) No ( ) Condition: Routinely Sampled: Yes ( ) No ( )	
<b>4. LEACHATE EXTRACTION WELLS</b> Yes ( ) No ( ) Functioning: Yes ( ) No ( ) Condition: Routinely Sampled: Yes ( ) No ( )	
<b>5. SETTLEMENT MONUMENTS</b> Yes ( ) No ( ) Located: Yes ( ) No ( ) Condition: Routinely Surveyed: Yes ( ) No ( )	

**Table 9-2. Example of post-closure monitoring form used by U.S. Army Corps of Engineers for CERCLA sites (cont).**

<b>COVER DRAINAGE LAYER</b>	
<b>1. OUTLET PIPES</b> Yes ( ) No ( ) Functioning: Yes ( ) No ( ) Condition:	
<b>2. OUTLET ROCK</b> Yes ( ) No ( ) Functioning: Yes ( ) No ( ) Condition:	
<b>DETENTION/SEDIMENTATION PONDS</b>	
<b>1. SILTATION</b> Yes ( ) No ( ) Areal Extent: Depth:	
<b>2. EROSION</b> Yes ( ) No ( ) Areal Extent: Depth:	
<b>3. OUTLET WORKS</b> Yes ( ) No ( ) Functioning: Yes ( ) No ( ) Condition:	
<b>4. Embankment</b> Yes ( ) No ( ) Functioning: Yes No Condition:	
<b>RETAINING WALLS</b>	
<b>1. DEFORMATIONS</b> Yes ( ) No ( ) Horizontal Displacement: Vertical Displacement: Rotational Displacement:	
<b>2. DEGRADATION</b> Yes ( ) No ( ) Description of damage:	
<b>VERTICAL BARRIER WALLS</b>	
<b>1. SETTLEMENT</b> Yes ( ) No ( ) Areal Extent: Depth:	
<b>2. PERFORMANCE MONITORING</b> Yes ( ) No ( ) Type of Monitoring: Frequency: Evidence of Breaching: Yes ( ) No ( )	
<b>GROUNDWATER SYSTEMS</b>	
<b>TYPE OF SYSTEM:</b> Containment ( ) Treatment ( ) Functioning: Yes ( ) No ( ) Condition: Routinely Monitored: Yes ( ) No ( )	

**Table 9-2. Example of post-closure monitoring form used by U.S. Army Corps of Engineers for CERCLA sites (cont).**

<b>PERIMETER DITCHES/OFF-SITE DISCHARGE</b>	
<b>1. SILTATION</b> Yes ( ) No ( ) Areal Extent: Depth:	
<b>2. VEGETATION GROWTH</b> Yes ( ) No ( ) Areal Extent: Type:	
<b>3. EROSION</b> Yes ( ) No ( ) Areal Extent: Depth:	
<b>4. DISCHARGE STRUCTURE</b> Yes ( ) No ( ) Functioning: Yes No Condition:	
<b>FENCING</b>	
<b>FENCING DAMAGE</b> Yes ( ) No ( ) Description of damage:	
<b>PERIMETER ROADS</b>	
<b>ROAD DAMAGE</b> Yes ( ) No ( ) Description of damage:	
<b>SITE ACCESS</b>	
<b>ACCESS RESTRICTIONS</b> Yes ( ) No ( ) Description:	
<b>GENERAL</b>	
<b>1. VANDALISM</b> Yes ( ) No ( ) Description of damage:	
<b>2. CHANGED SITE CONDITION</b> Yes ( ) No ( ) Description:	
<b>3. LAND USE CHANGE</b> Yes ( ) No ( ) Description:	
<b>INTERVIEWS</b>	
<b>1. INTERVIEW ON-SITE WORKERS</b> Yes ( ) No ( ) Problems: Suggestions: Attach report:	
<b>2. INTERVIEW NEIGHBORS</b> Yes ( ) No ( ) Problems: Suggestions: Attach report:	
<b>3. INTERVIEW LOCAL OFFICIALS</b> Yes ( ) No ( ) Problems: Suggestions: Attach report:	

**Table 9-2. Example of post-closure monitoring form used by U.S. Army Corps of Engineers for CERCLA sites (cont).**

<b>REVIEW DOCUMENTS</b>	
<b>1. GROUNDWATER MONITORING RECORDS</b> Abnormalities: Yes ( ) No ( )	
<b>2. GAS GENERATION RECORDS</b> Abnormalities: Yes ( ) No ( )	
<b>3. SETTLEMENT MONUMENT RECORDS</b> Abnormalities: Yes ( ) No ( )	
<b>4. OPERATION AND MAINTENANCE PLAN</b> Plan in Place? Yes ( ) No ( ) Plan is Being Followed? Yes ( ) No ( ) Plan is Adequate? Yes ( ) No ( ) Optimization is Being Considered? Yes ( ) No ( ) Systems with Optimization Potential? Yes ( ) No ( )	

## 9.2 Cover System Maintenance

### 9.2.1 Overview

There are a number of routine activities that should be conducted as part of a long-term cover system maintenance program. These activities can generally be divided into the following major categories:

- vegetation-related activities;
- erosion-related activities;
- subsidence-related activities;
- other surface layer performance related activities;
- drainage layer related maintenance;
- surface-water related activities; and
- monitoring system-related activities.

These maintenance categories, which are discussed in more detail below, are not all inclusive for a facility. For example, site access control must also be maintained. In addition, for facilities with gas control systems, there may be certain maintenance activities required under the CAA. Further, there are likely other site-specific categories that need to be considered for waste containment and remediation sites put to beneficial use.



### **9.2.2 Vegetation-Related Maintenance**

Cover system vegetation maintenance may include periodic irrigation and fertilization, as least until vegetation is established, reseeding or replanting areas where vegetation has failed, cutting young trees before they get too large and their roots disturb the cover system components, and mowing. In virtually all cases, some degree of maintenance is necessary until the cover system reaches a state of equilibrium with its inherent environment. Maintenance of cover system vegetation is especially important for alternative cover systems that rely primarily on ET to limit percolation.

As discussed in Section 2.2.3, grasses on cover systems located in humid or temperate climates are usually mowed periodically to discourage the growth of deep-rooted plants, such as trees and certain shrubs. Deep-rooted plants are usually undesirable because their root systems could plug the drainage layer or penetrate and increase the hydraulic conductivity of the hydraulic barrier, if the barrier consists of only a CCL or GCL without an overlying GM. Trees can also create problems if they are blown over, uprooting large masses of soil and leaving a crater in the surface. Many shrub species are shallow-rooted, do not require trimming/cutting, and are sufficiently dense in their ground surface covering so as to prevent larger (deep-rooted) trees and bushes from germinating. Mowing on a regular basis is expensive, thus its avoidance by proper selection of shrub vegetation is an important design consideration.

### **9.2.3 Erosion-Related Maintenance**

Cover system erosion, primarily by water, has been a problem for a number of cover systems, as discussed in Section 2.2.5.1. It is important that significantly eroded areas be repaired in a timely manner after they are observed to prevent progressive erosion and damage to cover system components. Furthermore, it is easier to repair erosion rills prior to their development into larger erosion gullies. As discussed in Section 2.2.5.2, rills can be removed by tilling the soil surface. Gullies, on the other hand, generally cannot be repaired this way. Instead they should be cut out and backfilled with soil that is blended into the adjacent soil.

### **9.2.4 Subsidence-Related Maintenance**

As cover system settlement occurs, the surface grades of the cover system often decrease. If the grades decrease substantially (and more than considered for design), the flow of water within any cover system internal drainage layer and/or the flow of stormwater runoff may be impeded. Regrading of a cover system is difficult not only from soil availability and placement perspectives, but also from complications arising from pipes, piers, and other appurtenances extending through the cover system. For example, a MSW landfill with an active gas extraction system and leachate recirculation system may have numerous wells penetrating its cover system and surface piping extending across the cover system, thereby requiring relatively small construction equipment for maintenance regrading. Production rates with small equipment are low. Obviously, the surface vegetation must be replaced after maintenance grading, and, in the interval before vegetation is established, a temporary erosion control material may be necessary.

The cover system may also exhibit localized differential settlements that cause ponding of water and breaks in cover system piping. The existence of such depressions may lead to localized areas with increased rates of percolation through the cover system. Whenever differential settlement is visually observable, maintenance is necessary. If the cover system drainage layer, hydraulic barrier, or finer-soil-to-coarser-soil interface, in the case of a capillary barrier, has also subsided, the cover system will need to be reconstructed to bring the surface of these layers to grade. For a capillary barrier, this repair must be carefully constructed, as described in Section 3.6.1, to reduce the potential for preferential pathways for infiltrating water. Besides causing localized increases in percolation, cover system depressions also generate tensile strains in the cover system components. As discussed in Section 2.5.2.5, tensile strains can cause barrier materials to fail if the strains are excessive. Depending on the shape of the depression, and the resulting tensile strains, a barrier material may need to be replaced in the depressed area. In other words, bringing the surface of a CCL to grade in a depressed area will not be sufficient if the CCL has failed due to excessive tensile strains. Instead, the barrier would have to be repaired in some manner (e.g., by reconstructing the CCL or by bringing the CCL to grade and placing a GM over the repaired area).

In addition to the above, subsidence-related maintenance may include adjusting the boots around penetrations of the cover system barrier as the cover system settles.

### **9.2.5 Other Surface Layer Related Maintenance**

To minimize percolation through the cover system, the integrity of the surface layer should be maintained. Significant cracks or holes in the surface layer should be repaired, especially for cover systems with ET or capillary barriers. The cracks may be caused by wet-dry cycles or may be an indication of slope instability. Holes may be caused by burrowing animals.

### **9.2.6 Drainage Layer Related Maintenance**

Drainage layer maintenance generally consists of clearing outlets of any obstacles, such as debris, sediment or ice.

### **9.2.7 Maintenance of Surface-Water Management System**

Maintenance of surface-water (i.e., stormwater) management systems is often required after significant storm events. Excess sediment or other obstacles in drainage channels should be removed, and damaged channel linings should be repaired. In areas where erosion has undercut drainage channels (see Figure 7-19), the channels should be reconstructed. It is important that these undercut areas are not just backfilled with soil if they are gully-like. As discussed above in Section 9.2.3, gullies have to be cut out and reconstructed. Otherwise it is easier for the gully to reform along the same flow path.

Drainage downchutes, outlets, energy dissipaters, and other areas where cover system stormwater flows concentrate or substantially change energy state often require regular maintenance and repair. These types of structures deserve careful attention during post-closure

monitoring and need to be maintained in good operating condition. Gross et al. (2002) provide several examples of damage to these types of structures resulting from stormwater flows.

### **9.2.8 Maintenance of Cover Monitoring System**

Maintenance of the cover system monitoring system may include period re-calibration of monitoring devices, replacement of batteries in data acquisition systems, and replacement of damaged or non-functioning monitoring system components.

## **9.3 Site End Use**

### **9.3.1 Overview**

Increasingly, beneficial post-closure land uses are being considered in the design of cover systems for waste containment facility closures and remediation sites. As of February 2001, more than 190 cleaned up CERCLA sites have been returned to productive use (EPA, 2001b). EPA's Superfund Redevelopment Initiative reflects the Agency's belief that contaminated sites should be cleaned up in a manner that is protective for reasonably anticipated future land use (EPA, 1999a; EPA, 2001a). EPA does not favor one type of reuse over another, as land use is a local decision. Further, the Agency believes that reuse should help to ensure proper maintenance of the remedy (or cover system for waste containment sites) while providing tangible benefits to key stakeholders, especially the surrounding community. The possible benefits of reuse include (EPA, 1999a):

- *“Positive economic impacts for communities living around the site including new employment opportunities, increased property values, and catalysts for additional redevelopment activities;*
- *Stakeholder acceptance of the municipal landfill presumptive remedy because of potential time and cost savings, and increased involvement in the restoration and redevelopment process;*
- *Enhanced day-to-day attention, potentially resulting in improved maintenance of remedy integrity and institutional controls; and*
- *Improved aesthetic quality of the area through discouragement of illegal waste disposal or trespassing on restricted portions of the site, as well as increased upkeep of the site by future site occupants.”*

For CERCLA sites, EPA must balance this preference for future land use with other technical and legal provisions, including ARARs. Only if the remedy is anticipated to achieve cleanup levels that allow the site to be available for the reasonable anticipated future land use, will EPA support that reuse.

The reuse selected for a given site is a function of a number of factors, including the stakeholders, site features, environmental considerations, site ownership, land use considerations and environmental regulations, community input, and public initiatives. These factors are

discussed in EPA (2001a). The three major categories of site end use that have been employed at waste containment facilities and remediation sites are: (i) ecological enhancement; (ii) recreational reuse; and (iii) industrial and commercial reuse (EPA, 1999a). Each of these categories is discussed in more detail below, and case histories illustrating these categories are presented. Additional detail is provided in EPA publications (available for download at the EPA website <http://www.epa.gov/superfund/programs/recycle/newdocs.htm>) on the recreational reuse (EPA, 2001b) and commercial reuse (EPA, 2002) of CERCLA sites. About half of the 190 CERCLA sites mentioned above that had been developed by February 2001 are being used for industrial or commercial purposes (EPA, 2002).

Whatever the type of end use, there are site design issues, such as settlement, gas management, and surface-water management, which are often common to many sites. In addition, some types of sites and end uses may have more issues than others. For example, when developing a former MSW landfill site as a retail shopping complex, there is extra concern about foundation settlement and gas migration to enclosed structures. If the site were developed as wildlife habitat, settlement and gas migration would likely not be as much a concern.

The selected end use can have a significant impact on cover system design. For example, if a site is to be used for a golf course or other facility with a vegetated surface layer that requires irrigation, the cover system may require an internal drainage layer and a barrier that includes a GM to control percolation through the cover system. It is important that the site end use be considered during the design phase of the cover system so that any special features needed to support the post-closure use can be incorporated into the cover system at that time. It can be significantly more expensive to retrofit a constructed cover system to support a specific site end use than to design the cover system to support the specific end use from the start. These end-use designs will have their own monitoring and maintenance requirements. Personnel maintaining the end-use facility should be aware of the maintenance requirements related to the prior disposition of the facility (i.e., waste containment facility or remediation site).

### **9.3.2 Ecological Reuse**

Closed waste containment and remediation sites located in ecologically significant areas have been used as wildlife restoration areas or wetlands. Besides providing a nurturing environmental for plants and wildlife, wetlands filter sediments and contaminants from surface water and can absorb floodwaters, which reduces the flooding potential for lowlands.

### **9.3.3 Recreational Reuse**

Closed MSW landfills are a natural fit for reuse as recreation areas because they typically have a large surface area, and the cover system can generally be contoured to meet the specifications for recreational facilities, such as ball fields or golf courses (EPA, 2001b). Recreational reuse has included trails for hiking, mountain biking, or horseback riding, camping facilities, picnic areas, parks, playgrounds, sledding areas, playgrounds, ball fields, and golf courses. In many cases, a site that will be developed for recreational purposes will support more than one type of recreational activity. For example, a site developed as a general use park may also accommodate

DRAFT - DO NOT CITE OR QUOTE

sports fields, playgrounds, trails, or other recreational features. In other cases, recreation may be secondary to a primary use, such as a commercial development. Detailed information on the development of recreation facilities over waste containment facilities and remediation sites is presented in EPA (2001b) and is not repeated herein.

#### **9.3.4 Industrial and Commercial Reuse**

The beneficial use of closed sites is particularly attractive in areas where developable real estate is limited and expensive. In major urban areas, closed waste containment and remediation sites are increasingly viewed as offering potential for traditional urban developments, such as office parks and retail centers. In such settings, these facilities may not be suitable for ecological or recreational use. Industrial and commercial reuse has included parking lots, restaurants, retail shopping stores or complexes, office buildings, intermodal transportation facilities, port cargo handling facilities, and airports.

One impediment to the design of structures over closed waste containment facilities or remediation sites is that the underlying materials (waste or contaminated materials) may have much different properties than soil. The foundations for these structures should be carefully designed to be protective of the cover system and prevent structural damage. If the waste or contaminated material is anticipated to experience large settlements (e.g., as is typical for MSW), the use of shallow building foundations (e.g., spread footings, reinforced concrete mats, grid foundations with column footings tied together with a system of grade beams and usually an integrated concrete floor) is generally limited to small lightly loaded structures that can tolerate some differential settlements (Dunn, 1995). These shallow foundations are typically located above the cover system barrier layer and contain more reinforcing steel than is required for foundations on conventional sites. Structures on shallow foundations can also be designed to accommodate differential settlements by using tilt-up wall construction, where both the wall sections and the footings are broken up into discrete sections with control and leveling joints between them, by casting the slab in separate sections connected by cable linkages, or by other means (EPA, 2002).

If settlements are anticipated to be too high, site improvement techniques can be considered. Dunn (1995) offers these techniques for reducing the total settlement of structures constructed over MSW landfills:

- *allowing the MSW to reach an acceptable level of decomposition, either by delaying construction or enhancing decomposition ...;*
- *supplemental compaction of the MSW, which is usually limited to relatively shallow MSW depths of no more than two or three meters;*
- *surcharging, with settlement monitoring;*
- *dynamic compaction; and*
- *grouting or fly-ash injection.*

If these techniques are unfeasible, deep foundations can be considered.

Heavier structures over waste materials may need to be supported on deep foundations, which are typically piles driven into competent supporting materials below the waste, though drilled piers are also sometimes used. Deep foundations may not be appropriate for sites with a liner system, with wastes that are difficult to drive or drill through, or that have an uncontaminated aquifer that could be impacted by the foundation construction (EPA, 2002). Where deep foundations penetrate the cover system, the penetrations need to be carefully designed to control infiltration and gas emissions. In some cases, structures on pile or pier foundations may settle less than the surrounding area, and gaps may form between the structure and adjacent features (e.g., roads, parking lots, etc.), potentially damaging structure entryways and utilities. Periodic maintenance of these structures may include site regrading, repair of entrances, and adjustment of utilities.

Shallow and deep foundations on waste containment or remediation sites are designed using standard geotechnical methods with consideration of settlement, bearing capacity of shallow foundations, capacity of deep foundations, and downdrag due to waste settlement. In addition to these geotechnical considerations, environmental factors, and especially gas migration, must be considered. Gas migration to enclosed structures is especially a concern with site reuse. Sites that are expected to produce significant amounts of gas may not be good candidates for industrial or commercial uses, unless the gas is well controlled. For this case, there are generally two systems for gas control: (i) a gas management system that is usually incorporated into the containment system; and (ii) a gas protection system for the structure that is usually independent of the gas management system. Gas protection techniques used for industrial and commercial facilities include (EPA, 2002):

- *“Construct floor slabs with convex bottoms to prevent methane from pooling below the structure.*
- *Place an impermeable (gas resistant) geomembrane or other hydraulic/gas barrier under the structure or within the building’s floors. This is especially important for sites likely to experience settlement that may disrupt the cover.*
- *Engineer an air space below a structure to allow for gas detection and venting, as well as to facilitate inspection and maintenance of the cover.*
- *Place gas detectors in closed structures to warn of potential gas buildup.*
- *Install vent fans to remove methane buildup from the structure.*
- *Ensure that the design of utilities does not allow for gas migration along utility conduits. One approach is to attach utility service entrances to the outside wall of the structure so they do not penetrate the floor slab, which may create a pathway for gas entry.”*

Additional detail on the development of commercial facilities over waste containment facilities and remediation sites is presented in EPA (2002) and is not repeated herein. Most of this information is also applicable to the development of industrial facilities over these sites.

### 9.3.5 Case Histories

Several published case histories of different site end uses for different types of facilities are presented below. Additional case histories are presented in several EPA publications (1999a, 2001b, 2002), which can be downloaded from the Agency's website at <http://www.epa.gov/superfund/programs/recycle/product.htm>. The website also include individual case histories of the reuse of some CERCLA sites.

#### *Bowers Landfill*

As described by EPA (1999a, 1999b), the 5-ha Bowers Landfill site was located in a former rock quarry within the Scioto River floodplain in central Ohio. Municipal, chemical, and industrial wastes were disposed in the landfill. Until the remedy was constructed the site was flooded an average of 29 days/yr, and contaminants from the site were carried to groundwater and the river. The remedy included removing surface debris and sediments, constructing a cover system that included a CCL barrier and gas collection system over the landfill, and creating 3-ha of wetlands between the landfill and the river. The wetlands not only provide a protective buffer between the landfill and river, but also provide habitat for numerous species of plants, birds, and other wildlife.



**Figure 9-1. Constructed Wetlands at Bowers Landfill Site.**

### *Three Landfills in Florida*

Mackey (1996) presents case studies of different end uses that were implemented at three closed landfills in Florida. The first site, the Key Largo Landfill Facility, was developed as a nature preserve. This 6.0-ha facility is surrounded on three sides by the Florida Crocodile Refuge, which is maintained by the U.S. Fish and Wildlife Service (USFWS) and provides habitat for several endangered species. The cover system design consists of, from top to bottom:

- 0.15-m thick vegetated topsoil surface layer;
- 0.30-m thick limerock protection layer;
- GC drainage layer;
- 1.0-mm thick textured HDPE/VLDPE/HDPE GM; and
- 0.15-m thick compacted limerock foundation layer.

To enhance the value of the facility as a wildlife preserve, the cover system was vegetated with native plant species and feral cats and certain exotic plants were removed.

The second site, the 13.2-ha Sanlando Landfill Facility, was developed into a softball complex. During the selection of an end-use for the site, it was anticipated that a softball complex would get significant use because it would be located adjacent to a park already used by the community and there had been a large growth in population in the vicinity of the facility. Due to the numerous cover system penetrations that would be required to install poles for fencing and lights, piers for buildings constructed over the landfill, and utility conduits, the design engineers decided to use a CCL hydraulic barrier rather than a GM barrier over the majority of the facility. However, beneath buildings, a 0.5-mm thick PVC GM barrier was installed to reduce the potential for gas migration into the structures.

The third site, the Dyer Boulevard Landfill Facility, occupies 260 ha and includes three large disposal areas, one area containing MSW, one area containing construction and demolition waste (C&DW), and the remaining area containing mixed waste, waste and C&DW. This facility was developed into a multi-faceted sports and recreation complex that includes basketball courts, soccer fields, tennis courts, an observatory mound, picnic areas, canoe rentals, and multi-purpose trails for pedestrians, joggers, bikers, and horses. A specific design feature was incorporated into the cover system over the C&DW area. The end use of this area was a mountain bike challenge course. However, there was concern that the mountain bikes would cause rutting and erosion of the cover soils. To monitor the effect of the activity on the cover system and limit any significant impact, a GT reinforcement layer was placed beneath the mountain bike trails. The purpose of the GT is twofold: (i) to reduce rutting; and (ii) to alert maintenance personal that significant rutting has occurred (and that the cover system must be repaired).



### *Chisman Creek Superfund Site*

As described by EPA (1999a, 1999c, 2001b), the 11-ha Chisman Creek Superfund site is located in York County, Virginia near Chisman Creek, a tributary of Chesapeake Bay. From 1957 to 1974, more than 500,000 tonnes of fly ash from a coal-fired power plant was deposited into abandoned sand and gravel pits on the site. The fly ash was not covered, and eventually resulted in groundwater, surface-water, and soil contamination. The remedy included constructing a cover system over the fly ash and installing a leachate collection and treatment system in the oldest and deepest pit. Because fly ash has low compressibility and doesn't generate gas, fly ash fills can be ideal sites for structures.

The site, plus some adjacent property, was developed into two sports parks, with two lighted softball fields, four soccer fields, restrooms, vending facilities, equipment storage facilities, and a parking area (Figure 9-2). The cover system was engineered to serve as a foundation for the park facilities and graded to accommodate park structures. The cover system design consists of, from top to bottom:

- 0.15-m thick vegetated topsoil surface/protection layer;
- 0.15-m thick sand drainage layer;
- 0.3-m thick CCL; and
- 0.3-m thick soil/ash mixture.



**Figure 9-2. Softball Fields at Chisman Creek Superfund Site (from EPA, 1999c).**

Precautions, such as placing underground utilities in oversized trenches filled with clean fill, were taken to protect future workers from coming into contact with the fly ash.

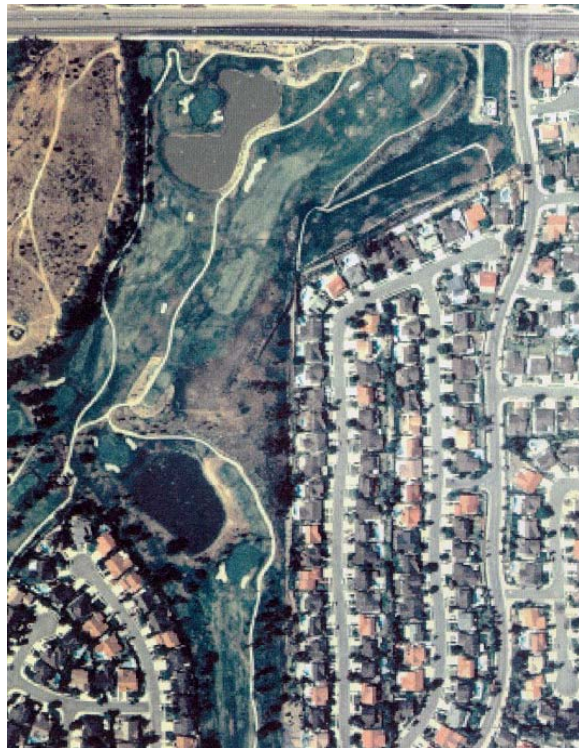
### *McColl Superfund Site*

As described by Collins et al. (1998), the 8.8-ha McColl Superfund site is located in Fullerton, California and includes 12 unlined pits of sludges and other wastes from production of high-octane aviation fuel (Figure 9-3(a)). In the 1950s and 1960s, three pits were covered with diesel-oil based drilling mud and six pits were covered with soil to control odor and gaseous emissions. The site was placed on the NPL in 1982. The remedy for the site was designed around its end use as part of the Los Coyotes Golf Course and wildlife sanctuary (Figures 9-3(b) and (c)). The remedy includes a multi-component soil and geosynthetic cover system designed to control infiltration and emissions of thiophene compounds, retaining walls to stabilize steep slopes adjacent to the pits, and a soil-bentonite slurry wall. In areas that had been covered with soft drilling muds, a lightweight geocell-reinforced cover system was used. Beneath the golf course, the cover system was geogrid reinforced and included a cobble protection layer to minimize the potential for human intrusion. For both conditions, the cover system included an HDPE GM/GCL barrier underlain by a sand gas collection/foundation layer.

(a)



(b)



(c)



**Figure 9-3. McColl Superfund Site: (a) Before Closure; (b,c) After Development as a Golf Course and Wildlife Sanctuary ((c) was downloaded from an EPA website at [http://www.epa.gov/superfund/programs/recycle/briefs/ca\\_brief.htm](http://www.epa.gov/superfund/programs/recycle/briefs/ca_brief.htm)).**

### *Raymark Superfund Site*

As discussed by EPA (1999a, 1999d, 2002), the 14-ha Raymark Superfund site is located in Fairfield County, Connecticut and was operated from 1919 to 1989 as a manufacturing facility for automotive parts and products. Waste generated during the assembly process was disposed in on-site lagoons. As these lagoons reached capacity, they were dredged and the dredged materials were used as fill for construction on over 70 local properties, including school playing fields, recreational parks, and commercial and residential properties. The dredged materials contained lead, asbestos, PCBs, dioxins, and 60 other hazardous substances, and subsequently contaminated soil and groundwater. The remedy for the contaminated properties consisted of relocating contaminated materials back to the Raymark Superfund site or constructing cover systems over them. On the Raymark property, buildings and structures within a 6-ha area were decontaminated and demolished, a groundwater pump-and-treat system was installed, and the on-site and off-site contaminated soils were collected and contained with a cover system. The cover system included GM/CCL hydraulic barrier and underlying sand gas collection layer. Between 0.9 and 3 m of clean fill were placed over the hydraulic barrier to facilitate site development and protect the barrier.



**Figure 9-4. Conceptual Drawing of Future Shopping Center at Raymark Superfund Site (EPA, 1999d).**

The proposed end-use for the Raymark Superfund site is a 3-ha retail shopping center (Figure 9-4). Prior to construction of the cover system, the site was improved to enhance its geotechnical properties. In-place soils and waste were stabilized using dynamic compaction or surcharging, and peat deposits were dewatered using wick drains. A 0.2-ha platform foundation for the shopping center has been constructed. The platform is supported by 277 30-m long piles that penetrate the cover system.



### *Denver Radium Superfund Site*

As described by EPA (1999e, 2002), operable unit (OU) 9 of the Denver Radium Superfund site is a 7-ha property located in Denver, Colorado that was first used for industrial activities in 1886, with the construction of a smelter. The site was subsequently used for other industrial activities, including cyanide leaching, zinc milling, radium ore processing, minerals recovery, manufacturing and servicing of batteries, oil reclamation, and brick manufacturing. As property ownership, industrial activities, and land use changed, radioactive by-products were often left in place, used as fill or foundation material, or otherwise mishandled. At the time the site remedy was selected, the site soil was contaminated with radium-226, arsenic, zinc, and lead.

The remedy for OU 9 consisted of excavating radioactive materials found at the site and shipping them to an offsite disposal facility and relocating 13,000 m<sup>3</sup> of metals-contaminated soils to four unlined containment cells covered with asphaltic concrete. The primary risks to human health and the environment posed by the soils are related to the ingestion or inhalation of the metals. Since the metals in the soils are only slightly soluble, percolation of water through the soils is not likely to cause the metals to migrate. Thus, the cover systems for the four cells were designed to minimize contact with the waste, rather than to minimize percolation. The remedy was developed concurrently with the design of the site reuse. The site has been developed with a large retail store and parking lot (Figure 9-5). The uncontaminated spaces between the four containment cells were used for utility corridors, and the asphaltic concrete cover systems were incorporated into the parking lot. The store, itself, was constructed on uncontaminated soil.



**Figure 9-5. Part of the Denver Radium Superfund Site was Developed with a Retail Store (EPA, 1999e).**